Biotechnology, Biodiversity, and Sustainable Agriculture: A Contradiction?

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This paper describes (1) the status of the use of biotechnology for conservation and utilization of biodiversity and interaction among them, (2) the status of use of biotechnology for sustainable agriculture, (3) how real are the contradictions among biotechnology, biodiversity and sustainable agriculture , (4) issues and efforts in resolving the concerns and contradictions, and (5) the way ahead. The author cited that it is not the science of biotechnology which is a subject of controversy, but the mode and nature of its applications, through techniques and technologies which could stir controversies. Biotechnology contributes to sustainable agriculture by reducing dependence on agro-chemicals, particularly pesticides, through the deployment of genes conferring resistance or tolerance to biotic and abiotic stresses. Discussing some concerns about risks posed by some aspects of biotechnology, the author stressed that the contradictions and risks surrounding the development and applications of biotechnology should be resolved scientifically and transparently for which individual countries should have the necessary research, technology assessment, impact monitoring, technology refinement, and adjustment capacities.

Introduction

The Convention on Biological Diversity (CBD) defined biotechnology as "any technology application that uses biological systems, living organisms, or derivatives there of, to make or modify products or processes for specific use." In a broad sense, the definition covers many of the tools and techniques, which have been commonly used in agriculture and food production, processing, and utilization. In a narrow sense, however, it encompasses DNA techniques, molecular biology, and reproductive technological applications dealing primarily with gene splicing and recombination, and genomics. In the present context, the narrow sense definition of biotechnology has been considered.

Biotechnology is already underpinning the sustainable development of agriculture, forestry, and fisheries, as well as the food and other primary product- related industries. It has tremendous potential for impacting global food security, human and animal health, environmental health, and overall livelihood of mankind (Serageldin 1999).

However, as in the case of any complex technology impacting wide range of processes and developments, the gains from modern biotechnology are accompanied with certain negative effects and concerns. The nature and extent of the positive and negative impacts will depend on the choice of the technique, place and mode of application of the technique, ultimate use of the product, concerned policies and regulatory measures, including risk assessment and management ability, and finally on the need, priority, aspiration and capacity of individual countries. What is applicable for

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commercial commodities in USA, Europe, and Japan may not be true for food-deficit low-income and other developing countries. We must know whose priorities ad agenda are we pursuing.

Science is always truth seeking, beautiful, and caring. The science of biotechnology is no exception. Molecular biology researches have beautifully been disentangling the thread of life which are being carefully rearranged to serve the humanity by thwarting diseases, poverty, and hunger. It is the application part of the science which, at times, generates contradictions, and not the science *per se*.

Modern biotechnology includes the following interdependent components: genomics, bioinformatics, transformation, molecular breeding, diagnostics, and vaccine technology. While there is general appreciation of the potential and impact of each of the components, controversies generally surround the transformation component resulting in Genetically Modified Organisms (GMOs), which may pose certain risks inherent to the technology. Other contradictions, socioeconomic in nature, are technology-transcending (Leisinger 2000). **Therefore, it is not the science of biotechnology which is a subject of controversy, but it is the mode and nature of its application, through techniques and technologies, which could stir contradictions.**

Biotechnology, especially as it deals with living organisms, with its veritable manifestations, has been a subject of extensive public debate. As regards biotechnology in relation to biodiversity and sustainable agriculture, the three are complementary, synergistic and interdependent, and not contradictory to each other.

Biodiversity is fundamental to both biotechnology and sustainable agriculture. Judicious, rational, and science- and need-based exploitation of genetic resources through biotechnological techniques should lead to sustainable agriculture. The controversy arises only when non-scientific, hasty, profit-motivated, inhuman and unethical applications of biotechnology, and use of biodiversity are contemplated. Scares like 'terminator gene' and the 'negative' application of gene use restriction technologies (GURTs) are seen as moves toward monopolistic control of the thread of life by a few global companies.

It has to be pointed out that the issues of food safety and biosafety could be matters of real contradiction. Horizontal gene transfer through genetic engineering is a possibility, posing threat to biodiversity and sustainability. However, with the scientific assessment of the risk and adoption of preventive and corrective measures, the risks (contradictions) could be avoided or at least minimized. With the overwhelming evidence of high synteny among genomes of highly diverse organisms, such as flies and mammals, the risk from horizontal gene transfer gets diluted. As new results and understandings build up, which is happening exponentially, the risks and contradictions must be assessed critically and continually on a case-to-case basis.

This paper briefly describes 1) the status of the use of biotechnology for conservation and use of biodiversity and interaction among them; 2) the status of use of biotechnology for sustainable agriculture; 3) how real are the contradictions among biotechnology, biodiversity, and sustainable agriculture; 4) issues and efforts in resolving the concerns and contradictions; and 5) the way ahead.

Biotechnology and Genetic Resources

The genetic resources (and the full spectrum of genetic diversity contained in them) of plants, animals, and microbes constitute the raw material for all biotechnology–based research, technology development, and creation of new products. The molecular tools of biotechnology have accelerated precision breeding by identifying, isolating, cloning, and transferring desired genes from one species to another, from microbe to man, rendering the concept of Mendelian population as an obsolete concept. All the processes of genetic resources, namely: collection, conservation, evaluation, and utilization have been eminently impacted by biotechnology.

DNA libraries are a major supplement to germplasm conservation, let alone various *in vitro* conserved materials. *In vitro* conservation of plant species, which are asexually propagated or are infertile or produce recalcitrant seeds, is a common and important approach. Cryopreservation of semen, embryos, and even somatic cloning have greatly strengthened traditional conservation strategies in animals.

As regards evaluation, detecting single nucleotide polymorphism, identifying functions of specific genes and assigning functions to otherwise unknown genes is the ultimate in this field. Regarding germplasm use, besides distant hybridization, the production of transgenics (Table 1) and marker-aided selections have greatly enhanced the pace and precision of breeding activities. Today, nearly 40 million hectares are planted to transgenics, 33 million hectares of which fall in North America.

Table 1. Transgenic crops – the traits modified and their use

Crops	Genetic Modification	Purpose
Tomatoes, peas, peppers, Tropical fruits, broccoli, Raspberries, melons	Controlled ripening	Allows shipping of vine ripened tomatoes; improves shelf life, quality
Tomatoes, potatoes, corn, rice, lettuce, coffee, cabbage family, apples	Insect resistance	Reduces insecticide use and crop loss
Peppers, tomatoes, cucumbers	Fungal resistance	Reduces fungicide use and crop loss
Potatoes, tomatoes, cantaloupe, squash, cucumbers, corn, oilseed rape (canola), soybeans, grapes	Viral resistance	Reduces diseases caused by plant viruses and, since insects carry viruses, reduces use of insecticides and crop loss
Soybeans, tomatoes, corn, cotton, oilseed rape (canola), wheat	Herbicide tolerance	Improves weed control
Corn, sunflower, soybeans, rice	Improved nutrition	Increases amount of essential amino acids, vitamins or other nutrients in the host plants
Oilseed rape (canola), peanuts	Heat stability	Improves processing quality; permits new food uses for healthier oils

Source: Food Marketing Institute, The Hale Group/Decision Resources, Inc., Food Processing and Biotechnology Magazines, 2000.

Genomics - the science of deciphering the structure and function of a genome in totality - has emerged as the single most powerful discipline for detailed analysis of organization, expression, and interaction of an organism at the genome level. The structural (nucleotide sequences) and functional genomics have greatly expanded scientific understanding of biodiversity. In the year 2000, 141 projects of sequencing of a number of microbes, plants, and animals are underway and several of these are expected to be completed by the year 2003. The complete sequence of *Arabidopsis thaliana*, yeast, nematode, and fruitfly are already known and are helping gene transfer and understanding of evolution and gene functions in a big way. The recent declarations on the "working drafts" of the full genomes of rice (by Monsanto) and of human (by the Human Genome Project and Celera) are landmarks in the understanding of biodiversity and its use. The "working draft" of the rice genome will provide the data to the International Rice Genome Sequencing Project (IRGSP), enabling it to complete the genome sooner and at a lower cost.

Genomic analyses have revealed the conservation of gene sequences across life forms. The high synteny of rice genome with that of corn, wheat, other graminaceous plants, and also with other plants opens unlimited opportunities for developing products and technologies, not only in rice but also in other crops. The development in rice is particularly important for South, Southeast, and East Asia as the countries of these sub-regions produce and consume about 90 percent of the world's rice – the most important crop. The genomics will provide insight into the genetic control of complex processes and traits, thus paving the way for their improvement.

Biotechnology and Sustainable Agriculture

Biotechnology has been contributing to sustainable agriculture through the following ways:

- Increased resistance against biotic stresses (insect pests and diseases);
- Increased resistance against abiotic stresses (drought, cold, flooding, and problem soils);
- Bioremediation of polluted soils and biodetectors for monitoring pollution;
- Increased productivity and quality;
- Enhanced nitrogen fixation and increased nutrient uptake and use efficiency;
- Improved fermentation technology;
- Improved technologies for generating biomass-derived energy;
- Generation of high nutrient levels in nutrient-deficient staple crops such as rice.

Biotechnology contributes to sustainable agriculture by reducing the dependence on agro-chemicals, particularly pesticides, through the deployment of genes conferring tolerance or resistance to biotic and abiotic stresses. Carefully selected genes from related or unrelated genetic resources are integrated in otherwise desirable genotypes. Systematic pyramiding of genes allows integration of desirable genes in one genotype for different traits, such as tolerance to stresses, productivity, and nutritional quality.

Technology, including new varieties and breeds, is an essential element of sustainable agriculture. However, it is not the only element of sustainable agriculture.

Non-technological aspects such as governmental policy and will, institutional and infrastructural support, technology sharing and transfer mechanisms, and peoples attitude and awareness are equally, if not more important, in providing the needed conditions for absorption and successful exploitation of the technology toward sustainable agriculture.

Contradictions and Suggested Solutions

There are concerns about risks posed by some aspects of biotechnology. In the context of biodiversity and sustainable agriculture, the technology-inherent concerns are: 1) depletion of biodiversity and poor access to tailored genetic resources, 2) adverse environmental effect, and 3) negative effects on human health. The technology-transcending concern of widening of inequity and poor access to the new and emerging technologies and products on part of developing countries and resource-poor people and the majority of small farmers is a major contradiction.

It is feared that a handful of selected GMOs may replace diverse traditional cultures, causing increased genetic vulnerability. This concern is not different from the one caused by the Green Revolution varieties which had displaced indigenous varieties. In fact, biotechnology could be used for increasing biodiversity primarily through the channeling of genes from wild and weedy relatives into cultivated forms. A GMO developed for a specific purpose could fit a new niche. Thus, it will not only provide an ecological diversification but also a better option for management of risks.

Studies, however, are needed to study the impact of release of new improved genotypes in open populations on the gene and genotype frequency in the long term. There are good prospects of development of single-line (apomictic) hybrid varieties through the use of biotechnology. Besides socioeconomic implications (farmers can save seed for replanting of the hybrid), large-scale planting of apomictic hybrids can cause genetic erosion and enhance genetic vulnerability.

Horizontal gene transfer to unwanted sources, leading, for example, to the development of more aggressive weeds or wild relatives with increased resistance to environmental stresses or diseases would cause both genetic erosion and ecological imbalance. The extreme case of GM Bt corn pollen having lethal effects on the larvae of monarch butterflies if it lands on milkweed, the plant upon which they feed, had received wide attention. The loss of fish diversity associated with the escape of cultured transgenic fish and its mating with its wild counterpart appears to be a real threat. But, efficacies of such studies need to be ascertained more realistically before reaching definite conclusions. Multidisciplinary studies, involving genetics, agronomy, soil, microbiology, entomology, pathology, virology, among others, are needed to establish benchmark data and for continuous monitoring of the impact of such releases. Some caution that in the risk assessment process the “bar” should not be higher for genetically improved plants, and the protocols must cover all plants regardless of the process (Cook 2000).

Biotechnology and its application must always avoid accentuation of poverty and socioeconomic inequalities as these are strong cause for environmental degradation, political instability, and social unrests, which lead to greater unsustainability. The current trend of biotechnology development has generally been pro-rich as most of the biotechnological research and its application is in the hands of private sectors of developed countries, thus widening the gap between the rich and the poor. This trend is certainly not sustainable. This contradiction can be resolved if the pro-poor features of biotechnology are promoted. The public sector in developing countries must have the responsibility and capacity for the promotion of pro-poor features of modern biotechnology.

Some of the contradictions have arisen due to biotechnology garnering unduly high proportions of national resources for research and technology development at the cost of some of the conventional but vital programmes. Biotechnology must be seen only as an important tool to produce new products and services, which hitherto were generally considered difficult, if not impossible, in addressing challenges of food security and poverty alleviation. Biotechnology must not be seen as a panacea in itself, but only as an important and unique component integrated with overall national research and development infrastructures, institutions, policies, and programs.

The contradictions and risks surrounding the development and application of biotechnology should be resolved scientifically and transparently for which individual countries should have the necessary research, technology assessment, impact monitoring, technology refinement, and adjustment capacities.

Issues and Resolves

Biosafety and Risk Management

Biosafety means the safe and environmentally sustainable use of all biological products and applications for human health, biodiversity and environmental sustainability in support of improved global food security and livelihood. It involves assessing and monitoring the effects of possible gene flow, competitiveness, and the effects on other organisms as well as possible destructive effects of the products on the health of humans and animals. Biosafety policies and measures would thus have serious implications for the use of biotechnology for sustainable agriculture, food security, and biodiversity. For this purpose, each country, developed and developing, must have adequate and effective biosafety rules, regulations and legislations, capacity for detailed risk assessment and management, and mechanisms and instruments for monitoring the use and compliance of biosafety measures.

Introduction or import of GMOs and other genetically engineered products either through private or public sector channels should adequately be covered under legislation and handled with great care because of the threat of introducing completely new organism or genetic material. With the increasing focus on international transfers of GMOs, assessment of risk associated with the horizontal transfer of the 'new' gene in non-target species and development of resistance in pests and possible side effects on beneficial organisms should be undertaken most comprehensively and in a transparent manner. Given the wide implications of the biosafety concerns of biotechnology-led transformation of food and agriculture, FAO, and several other international organizations have been addressing the issue rather actively.

The signing of the CBD Biosafety Protocol in January 2000 in Canada is a landmark in the field of sustainable use of biotechnology and biodiversity management. The objective of the Protocol is to contribute to the safe transfer, handling, and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focussing on transboundary movements.

Recognizing that GMOs carry special or additional risks, the Protocol provides for their international regulation and establishes an internationally binding framework of minimum standards, which, together with national biosafety regulations, would provide the necessary biosafety net. The Precautionary Principle contained in the Protocol seeks that in the absence of scientific certainty, Parties should err on the side of caution.

In order to effectively implement the Biosafety Protocol, the following must be ensured by the concerned country: 1) full knowledge that GMOs will be crossing national boundaries and 2) capacity to assess the risks and take decisions regarding improving or banning the GMOs with or without conditions. While exporting Party is obliged to provide risk assessment, the importing Party must evaluate the risk assessment in order to make an informed, scientific decision. Therefore, the countries must have effective biosafety regulation, scientific capacity, and monitoring and enforcement capability.

The OECD, in collaboration with UNEP and UNIDO, coordinates a program of the harmonization of regulatory aspects of biotechnology and emphasizes the scientific evaluation of possible risks, which avoiding non-tariff barriers to biotech products. The Office International des Epizooties (OIE) is a global clearing house of occurrence and control of animal diseases and harmonizes regulations for trade in animals and animal products among Member Countries. The OIE Standards Commission publishes the Manual of Standards for Diagnostic Tests and Vaccines, including those genetically engineered.

Under the World Trade Organization (WTO), GMO related biosafety is covered by the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement), which recognizes international standards, guidelines, and recommendations, for instance, for food safety the standards and guidelines of Codex Alimentarius Commission are adhered to. The SPS Agreement is supplemented with the WTO Agreement on Technical Barriers to trade (TBT Agreement) which covers a large number of technical measures that seek to protect consumers from economic fraud and human, animal, and plant health problems not covered under the former.

As regards FAO, FAO/WHO Codex Alimentarius Commission is to protect the health of consumers and to coordinate and harmonize all international food standards and guidelines, including those related to foods derived from biotechnological applications. Scientific evidence and risk-analysis, in consort with other legitimate factors relevant to the health protection of consumers and promotion of fair practices in food trade are the basis of formulation and implementation of the food safety codes.

The *ad hoc* Intergovernmental Task Force on Foods Derived from Biotechnology was established by the Commission last year to assist in realizing the objectives of the CAC. In its First Session in Chiba, Japan, March 2000, it stressed the importance of a progressive and science-based exchange of views to reach a consensus in this area. The recent FAO/WHO Expert Consultation on Biotechnology had reaffirmed its support for technical assistance to developing countries regarding approaches to the safety assessment of foods and food components produced by genetic modification. The Task Force sought elaboration of two major texts: 1) general principles for risk analysis of foods derived from biotechnology and 2) specific guidance on the risk assessments of such foods. The Task Force also called for a list of available analytical methods to detect biotech-derived foods, a working paper on "traceability" and an information paper on "familiarity".

FAO's International Plant Protection Convention (IPPC) under its global mandate to prevent the introduction and spread of pests of plants and plant products, and promotion of their effective control, is concerned with evaluating the potential "pest" characteristics (including weediness) of GMOs. The Interim Commission on Phytosanitary Measures (ICPM) in October 1999 gave high priority to standard setting in relation to GMOs, in particular to risk assessment and testing and release of GMOs.

The draft Code of Conduct on Biotechnology, being finalized under the auspices of FAO's Commission on Genetic Resources for Food and Agriculture (CGRFA), includes biosafety as one of its four modules. Once negotiated, these will become biosafety protocol of the Convention on Biological Diversity (CBD). Concerned regional and international fishery organizations have adopted, in principle, codes of practice on the use of introduced species and GMOs. The FAO's Code of Conduct for Responsible Fisheries includes general principles for environmental assessment, constrained use, advanced notification, and the application of the Precautionary Approach. In close collaboration with OIE, FAO has been providing assistance to developing countries to improve their capacities in the effective application of international standards and agreement of the development and exchange of genetically modified fish species.

Access to Biotechnological Inventions, Products, and Information

Intellectual Property Rights (IPRs). The Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs) under the World Trade Organization (WTO) requires countries to grant patents for "inventions, whether products or process, in all fields of technology provided that they are new, involve in inventive step, and are capable of industrial applications." Under this agreement, most processes and many products, barring diagnostic, therapeutic and surgical methods for humans and animals and of plants and animals other than micro-organisms, are patentable.

The Intellectual Property Right (IPR) provisions promote inventions and their disclosers. These have particularly been stimulatory to the private sector, mostly in developed countries, to invest in research and development of biotechnology and have their results patented. The global market for agricultural biotechnology products is projected to increase to US$ 20 billion by 2010 from about US$ 0.5 billion in 1996. Private investment in agricultural research in the Organization of Economic Co-operation and Development (OECD) is now in excess of US$7 billion and accounts for about half the world's entire agricultural research investment. As expected, most privately-funded biotechnology research is targeted to those commodities, areas and markets where the economic benefits are maximum. Food staples and livelihood commodities of poorer people, often referred to as orphan crops and commodities, are generally excluded from the priorities of the private sector. Further, under the existing arrangements and current trend, the developing countries are required to pay to use a patented biotechnology produce and procedure. And several of the low-income food-deficit countries which may find it difficult to pay would be deprived of the new opportunity to meet even their essential needs.

It is also disturbing to note that there is a tendency to seek broad patents of generic nature. With no provisions for exemption to researchers, this trend will be counter productive to the original belief that the property rights regimes will stimulate inventions. The patent seekers should self-impose restraints from obtaining broad-based patents. Or else, the over-regulation of biotechnology could further widen the technology and income gaps between the rich and the poor.

For a different reason, public sector research institutions are now increasingly seeking protection of their biotechnological products and processes. Their protection regimes are designed essentially to protect their discoveries from being misused and for ensuring their availability to all stakeholders and bonafide users, especially the poor and small holders. Thus, as a whole, there will be different types of IPRs which must be internationally harmonized to facilitate effective sharing of the inventions. FAO Commission on Genetic Resources for Food and Agriculture advocates a judicious balanced blend of Farmers and Community Rights and Plant Breeders Rights encompassing farmers' privileges and researchers exemption. Most developing countries have included or are likely to include these elements in their national legislations on plant breeders rights and intellectual property rights. Several countries are making provisions for exclusion of "traitor" or "terminator" technologies. For instance, India's draft legislation on this subject has explicit provisions against the development, introduction, and use of "terminator" technology.

Recognizing that the IPRs are critical for growth of the biotechnology industry, realizing that under the TRIPS agreement it will be difficult to introduce new technologies originating elsewhere, and appreciating that IPR related issues are complex, with implications for trade, research priorities, technical investment, and access to biotechnology outputs, individual countries must have national debates involving various stakeholders to evolve a truly national view and perspective. The process will allow a critical assessment of the various issues, the national priority, existing and needed national capacity, and national goals and aspirations while preparing the national legislation. In view of the fast pace of developments in biotechnology research and application, each country may institute a national forum to internalise the dynamics of "gene revolution" in national plan and strategies.

Securing Benefits for Developing Countries. Several of the products and findings of biotechnology applications need to be exploited widely in the developing countries. Production and distribution of vitro-cultured disease free plantlets are already benefiting small farmers in developing countries. The virus resistant papaya transgenics developed in Hawaii are being shared with developing countries. Some of the international associations and agencies such as International Service for the Acquisition of Agro-Biotech Applications (ISAAA) are already assisting in sharing biotechnology products and techniques between developing and developed countries.

Regional and international initiatives such as those by the Consultative Group on International Agricultural Research (CGIAR), FAO supported regional biotechnology and research institutions and associations such as Asia Pacific Association of Agricultural Research Institution (APAARI) and the Global Forum for Agricultural Research (GFAR), should be further strengthened to undertake collaborative activities. Several countries lack basic research and technology development resources and infrastructure to even absorb introduced technologies, let alone the generation of new knowledge and technologies (Singh 1994). Such countries must give high priority to develop the minimum facilities. FAO and other UN agencies and donors should assist developing countries in building capacity for harnessing the latest developments in the field of biotechnology.

Monopolistic Control of Seeds and Other Products. The recent trends of mergers and takeovers between breeding (seed) companies, seed traders, chemical and food companies, health-related companies, and genetic engineering companies must be taken note of in context of the availability of and access on the part of small and resource-poor farmers, who are the majority, to desired seeds, genetic vulnerability, and household food security. Just 10 internationals have now cornered nearly 50 percent of the world's seed market. Given the stringencies of patent legislations, including the abolition of farmers' privileges of using saved seeds and the fear of "terminator seeds," individual governments must constitute their own product marketing rules, regulations, and legislations. It is a kind of *sui generis* system to meet their specific needs, containing effective checks and balances within the umbrella of international agreements. Countries may need antitrust enforcement policies for consumers protection when competition among industries is shifted because a particular multinational has acquired control of a market.

Access to Information. The information explosion in the field of biotechnology is being assimilated in various databases, but the information is not always available freely due to restrictions imposed by patent regimes. However, the recent decision of Monsanto and Celera regarding the sharing of the "working drafts" of full genomes of rice and human beings, respectively, is a major paradigm shift. Free access to information at all levels is fundamental to the rapid improvement of crop, livestock, forestry, and fish species. This is particularly important for the developing countries which are not in a position to generate new technologies, but are in a position to use them. Increasing databases on risks and possible negative effects of biotechnology should be available for consensus building and to enable the people at large to make informed choices. The Code of Conduct on Biotechnology for Genetic Resources for Food and Agriculture aims to ensure that informatics would not become a divider between the "haves" and "have nots."

Partnership between 'Seed Rich' and 'Gene Rich'

Molecular biology and genetical engineering research and development call for high-level investment of financial and human resources. Most developing countries are unable to commit the needed financial support. The costly biotechniques and products are thus out of the reach of the majority of poor institutions and people in the developing world. Private sector research and biotech development has therefore tended to be confined to well-endowed countries, communities, and commodities. It is unlikely that the private sector will serve a large number of resource-poor farmers in marginal and non-congenial settings. The public sector will therefore be required to develop technologies for such deprived people. However, the problems to be solved under such settings are rather complex and need advanced technologies for their redress. For instance, a poor rice farmer in rainfed areas needs technologies which will minimize his risks from too much or too little water, toxic soils, and low fertility and a large number of serious pests and diseases. To meet these challenges, the public sector will need advanced technologies which are often being developed by the private sector and are proprietary.

The marginal areas inhabited primarily by poor farmers and other people who are not poor in everything. Genetic resources evolved through ages and local knowledge accumulated and enriched over generations in such difficult habitats are unique and invaluable. A good part of genetic resources and the associated information and knowledge is conserved in public sector and national and international organizations, especially the CGIAR Centres. These unique resources are needed both by the public and private organizations and institutions to advance the frontiers of biotechnology, emphasizing the importance of synergistic collaboration between the two sectors. Recent developments and prospects of the genomics have further heightened the need and scope of effective complementarity and cooperation between the public and private sectors.

Both the public and private sectors will need 'free' access to the new tools and vast genetic resources for discovering new traits and the control of the intricate processes. One good example is the discovery and sharing of the ***Xa21*** gene, conferring resistance to ***Xanthomonas*** in rice. A rice germplasm collection from Mali (Africa), the development of near-isogenic lines by the International Rice Research Institute (IRRI) and the isolation and cloning of the gene by a "private" system, and patented in USA were integrated to produce the desired product, which is available to various developing countries at zero royalty.

In forging the public and private sector collaboration, the profit-making motive of the private sectors to recover the cost and for further invest, and the public sector's access to the new technologies and their use in a non-commercial manner should be rationalized. The public-private linkage in the genomics of rice and human is a major step towards accelerated research for identifying new genes and traits. The essentialities for sustaining this partnership could be satisfied through creating flexible proprietary rights arrangements. A material transfer arrangement (MTA) being advocated by the CGIAR system and supported by several national programs takes into account the needs and capacities of low-income subsistence farming settings, developing countries, and developed countries. Under such agreements, data and materials are freely available for research and there are provisions ensuring that recipients cannot obtain any form of intellectual property protection on the genetic stocks per se.

It is gratifying that the international community is continually providing guidance and mechanisms for equitable and judicious sharing of genetic materials and biotechnological products. The FAO's Code of Conduct on Biotechnology for Genetic

Resources for Food and Agriculture, the public sector-supported Genome Project and the International Rice Genome Sequencing Project and the private sector initiatives of Celera, Monsanto, and the like and the recently formed International Functional Genomics Working Group are geared to strengthen research, technology development, and information, technique and material sharing.

The cutting-edge discoveries in biotechnology, especially genomics, have increased the emphasis and scale of research collaboration between public and private sectors. Both in developed and developing countries, leading public sector institutions are seeking alliances with research wings of private companies. For instance, the University of Berkeley, California, U.S.A, is collaborating with Novartis in genomics research and Monsanto is collaborating with the Indian Institute of Sciences, (Bangalore) in molecular biology and genetic engineering. In the recent weeks, the collaboration of Monsanto with the International Rice Genome Sequencing Project in sharing the first "working draft" of the entire rice genome and the collaboration between Celera and the global human genome project for sharing the "working draft" of the entire human genome, are landmarks in private and public sector partnerships. This partnership must provide for equitability and benefit sharing mechanisms to the needs of all stakeholders, the gene-rich and the seed-rich and the rich and the poor. Such partnerships should particularly emphasise environmental sustainability, including biodiversity conservation, the needs of consumers and the aspirations of small farmers.

Ethical Aspects. Although all the contradictions must be resolved scientifically, the ethical and moral issues assume another dimension. These concerns are rooted in the fact that biotechnology is seen by some to 'interfere with the workings of nature and creation.' These concerns must be clearly balanced with the aspects of providing food to the hungry and dignity to the destitute. Mahatma Gandhi said to a hungry person that God can appear before him only in the form of bread. If biotechnology is the resort to grant the bread to the hungry, the ethic may demand the use of science. Mahatma also said nature has provided enough for everyone's needs but not for their greeds. The use of biotechnology to satisfy the greed of the greedy should clearly be discouraged, particularly when it raises ethical and moral concerns.

Some developing countries are suffering economically due to the substitution of their high-value export products such as food additives, flavors, vegetable oils and fats, and medicinal products with genetically engineered products (e.g., copra-quality oil rapeseed) by some developed countries. This phenomenon is not new. Think of the substitution of jute fibre and products by synthetic fibres causing economic and, indirectly, food security hardships to Bangladesh and other jute-producing and jute-exporting countries. Such contradictions could be settled through bilateral and multilateral negotiations on market sharing and pricing arrangements. Public awareness of the comparative values of naturally occurring conventional products versus engineered nonconventional products would also mitigate the problems.

Many of the ethics-related issues, such as 'patents on life forms,' cloning of mammalian species often referred to as "playing God'' are being debated in the context of IPR legislation and religious and cultural settings. These issues are more than just scientific issues. Public awareness; people's perception; and cultural backgrounds of the various scientific, socioeconomic, ethical, and moral issues will decide the nature and mode of use of modern biotechnology.

The Way Ahead

During the past 40 years, the global food production had more than kept pace with the increase in world population. Between 1960 and 1990, world cereal production doubled and per capita food production increased by 37 percent. Various predictions suggest that toward 2020, the trend will be maintained. However, it will be at a slower rate and per capita availability of food is estimated to increase around seven percent.

Despite the above trend of food production outpacing the population growth, a recent FAO technical interim report, titled "Agriculture: Towards 2015/2030," estimates that from the current level of about 790 million in 1995/97, there could still be about 575 million people suffering from chronic undernourishment in 2015. The number is expected to decline to 400 million in 2030. It may be recalled that the World Food Summit in November 1996 had targeted to halve the number of malnourished persons to 400 million by 2015. Thus, the current pace for meeting the target has so far been slow and the world might have to wait for another 15 years, until 2030 against 2015, before the numbers of undernourished are reduced by half.

World production of cereals, the principal source of food supplies, is projected to increase by almost one billion tons by 2030 from the current level of 1.84 billion tons. This increase even exceeds that of the past three decades. The dependence of the developing countries on imports of cereals is expected to rise from 107 million tons (net imports) in 1995/97 to 270 million tons in 2030.

The scenario in the Asia-Pacific Region is expected to be still of greater concern. While in the world as a whole the numbers of malnourished have declined, in the Asia-Pacific Region these had increased by three million, from 512 in 1990/92 to 515 million in 1995/97. The Region's dependence on cereals imports had increased from 33 million tons in 1965 to 80 million tons in 1998.

The Asia-Pacific Region, as the rest of the world, had witnessed the Green Revolution triggered through the semi-dwarf, lodging resistant, input-responsive, and period-bound varieties of rice, wheat, and other crops developed and widely adapted in the mid-60s and onward. The impact of the Green Revolution was most felt in this region and many doomsday predictions of mass hunger deaths were belied. The revolution brought unprecedented increases in productivity, production, irrigation, fertilizer use, food price deadline, rural prosperity, and food availability. Between 1995 and 1999, in the Asia-Pacific Region, cereal production and yield increased from 371 million tons to 987 million tons, and 1391kg/ha to 3258 kg/ha, respectively. Despite high population rise, the per capita calories intake increased from 2,039 kilo calories in 1965 to 2,693 kilo calories in 1998.

Primarily because of the high population pressure (57 percent of the world population) and the low access to the production resources (availability of arable land to an Asian farmer is one-sixth of that to a farmer in the rest of the world), the Asia-Pacific region accounts for nearly two-thirds of the world's malnourished. Of the world's about 200 million malnourished children, nearly 100 million dwell in South Asia alone.

Notwithstanding the outstanding role and impact of the Green Revolution in food security, rural income growth, and the much needed confidence of the politicians, policymakers and people in science-led growth and transformation of agriculture, there are several adverse impacts. The often cited weaknesses of the Green Revolution are:

- Bypassing the vast rainfed and dryland areas and commodities, thus exacerbating inequity;
- Environmental degradation and depletion of soil and water resources and quality caused due to inefficient and excessive use of irrigation, fertilizers, and other agrochemicals, and build up of pesticide resistance in major pests; and
- Loss of land races and overall erosion of biodiversity leading to greater genetic vulnerability.

Given the high present and projected population concentration, with agriculture being the backbone of national economy and main employer of the masses and having almost closed the option for horizontal expansion of cropped area in most developing countries of the region, the way ahead must be based on sustainable intensification of agriculture.

The Green Revolution path of agricultural intensification during the past over 30 years was certainly the most effective path to overcome the problems of widespread food insecurity and hunger. But, as already mentioned, it had its own pitfalls. Moreover, the Green Revolution varieties were developed using conventional Mendelian approaches whose impact is plateuing off, yield ceilings have been attained in the high yielding varieties (HYVs), and the approach had limited success in designing crops tolerant to complex stresses, such as drought. Convergence and integration of multiple desirable traits is a slow and highly uncertain process under the conventional approaches. The future path of intensification must avoid these pitfalls and limitations.

The way ahead must therefore seek the development of highly productive, efficient, resistant (to biotic and abiotic stresses) remunerative, quality-rich genotypes suitable both for congenial (irrigated) and non-congenial (rainfed/dryland) settings, which when blended with time-tested traditional technologies and appropriate policies, and synergized with modern information technology, should promote congruence of enhanced productivity, sustained and healthy ecology and environment, referred to as ecotechnologies (Swaminathan 2000).

On an average, in the recent years, the global, regional, and national level (in most countries) food production and availability had looked promising. And if everyone had full physical and economic access to the food, today there would not be hungry and malnourished person in the world. But, as noted, the averages conceal turbulent variations. Almost one-fifth of the population of the developing world is malnourished, ranging from less than 10 percent to over 40 percent from country to country. This paradox is linked with the inability of the poor to buy food. It is estimated that 1.3 billion people in the developing countries live in abject poverty, earning a dollar a day or less per person. No technological development should accentuate this paradox. Instead, the way ahead is to develop and promote pro-poor technologies which may enhance the income of poor people, improve their purchasing capacity and food self-reliance and augment the production of their commodities and agro-ecological settings, altogether to improve their food security (Persley 2000).

Food security should mean not only calories and protein adequacy and balance, but also adequacy of vitamins and especially vitamin A, zinc, iron, and iodine as well as balance of micronutrients to counter deficiency disorders prevalent in poor people. An estimated 180 million children, mostly in developing countries, suffer from the vitamin A deficiency that leads to two million deaths annually. Future food security strategies must address the issues of nutritional adequacy along with the issues of food security. In this context, the development of the "Golden Rice" holds great promise for Asian people where rice is the predominant food alongside widespread vitamin A and iron deficiency, especially among children and women. Golden Rice is a genetically transformed rice in which the transgenes enable the rice plant to modify certain metabolic pathways in its cells to produce the precursors to vitamin A, which otherwise was not possible.

It is fortuitous that as we have entered the new millennium and were seeking a technological breakthrough which may spearhead agricultural production in the next 30 years at a pace faster than that during the past 30 years (the Green Revolution era), modern biotechnology with multiple and far reaching potential has appeared on the horizon. As mentioned earlier, it is already being used for and has the potential to enhance yield levels, increase input use efficiency, reduce risk and depress effects of biotic and abiotic stresses, and enhance nutritional quality leading to increased food security, nutritional adequacy, poverty alleviation, environmental protection, and sustainable agriculture. Often referred to use 'Gene Revolution' or 'Bio-Revolution,' if judiciously harnessed, blended with traditional and conventional technologies and supported by appropriate policies, biotechnology can lead to Ever Green Revolution – synergizing the accelerated pace of growth and sustainable development.

The way ahead must map out the ways to optimize the benefits and minimize the negative effects of biotechnology on a case by case basis. Biotechnology should be kept in a balanced perspective by integrating it within the national research and technology development framework and using it as an adjunct to – and not as a substitute for conventional technologies in solving problems identified through national priority setting mechanisms. Priority setting should also take into account national development policies, private sector interests, market possibilities, public perception, and consumers views. Accordingly, various stakeholders, public sector, private sector, industries, NGOs, and civil societies should be involved in the formulation and implementation of national biotechnology policies, strategies, plans, and programs.

The technology-inherent as well as technology–transcending risks must be critically and scientifically assessed in a transparent manner. Capacities and measures should be in place to manage the risks, minimize the negative effects, and promote the positive impacts. Each country must have the necessary infrastructure, human resource, financial support, and policy for meeting the challenges and capturing the novel opportunities. Competence will particularly be needed in the formulation of country–specific rules and regulations on biosafety and intellectual property rights management regimes, along with commensurate financial, institutional, information, and human resources for their effective implementation.

The multiplicity of cooperation and management of development and application of biotechnology would seek a new way of governing the technology. The development of the "Golden Rice" amply substantiates this need. The inventors of the "Golden Rice" are professor Ingo Potrykus of the Institute for Plant Sciences, Swiss Federal Institute of Technology, Zurich, Switzerland, and Dr. Peter Beyer of the Centre of Applied Biosciences, University of Freiburg, Germany. The "Golden Rice" technology was developed with funding from the Rockefeller Foundation, the Swiss Federal Institute of Technology, the European Union, and the Swiss Federal Office for Education and Science, all costing about 100 million dollars. Other partners involved are Greenovation, which will help distribute this technology and is an offshoot of Freiburg University, and Zeneca Agrochemicals of AstraZeneca, which has bought the commercial rights to "Golden Rice" from Greenovation. Zeneca then licenses "non-commercial" rights back to the inventors and undertakes to help them improve the grain, deal with patenting issues, and guide Golden Rice through the costly testing and regulatory process.

The inventors of "Golden Rice" are supposed to distribute the rice free to government-run breeding centres and agriculture institutes, particularly in India, China, Thailand, and other rice-dependent Asian nations. However, some nearly 70 patents are involved in the development of the "Golden Rice." And, the discoverers of this rice are already frustrated with the veritable restrictions in taking the product to the malnourished who suffer from the vitamin A deficiency. Furthermore, other contradictions are also being voiced around "Golden Rice." These complexities clearly demonstrate that it is not enough to have a technology developed, but it is equally important, if not more, to have the nontechnological aspects, the enabling mechanisms, in place to allow a technology to perform. Such complexities are generally expected to be associated with biotechnological developments. Hence, the efforts at various levels must address concerns about "governing biotechnology," not just solving specific technical problems (Juma 1999).

The Asia-Pacific countries and regional programs of international organizations and institutions in the region must take cognizance of the commonality and unique features of the region while formulating their regional programs. For instance, more than 90 percent of the world's rice – the anchor of food security – is produced and consumed in the Asia–Pacific region. Therefore, it is most encouraging that, led by Japan, several Asian countries, supported by the Rockefeller Global Rice Biotech project, IRRI, and USA are engaged in analyzing rice genome. Due to strategic reasons, as mentioned earlier, Monsanto and other private companies have also supported rice genomics work. Similar initiatives are also needed for other commodities, whose more than 70 percent of the global production is confined to this region. These include jute, rubber, coconut, oil palm, mango, and a large number tropical fruits and vegetables, buffalo, aquaculture and several forestry and agro-forestry species.

Another unique feature of the Asia-Pacific region is high concentration of small farmers. While the region accounts for 73 percent of the World's farming households, its per caput availability of land is nearly one-sixth of that in the rest of the world. Therefore, the application of biotechnology in the developing Asia-Pacific region should be geared to improve the commodities and production systems linked with small farmers. Further, intellectual property right regimes should have provisions not to deny the access of resource-poor small farmers to needed biotechniques and products.

In the Asia-Pacific region, there is great inter-country diversity in the preparedness for judiciously harnessing modern biotechnology. On one hand, there are countries like Australia, Japan, New Zealand, and the Republic of Korea which have comprehensive research and regulatory mechanisms and provisions for rational development and application of biotechnology. On the other hand, most of the low-income food-deficit countries, although keen to use the new technology, are rather ill-prepared for capturing the opportunity. Then there are a good number of countries such as China, India, Malaysia, Thailand which have fairly elaborate technical capacity, but would need to strengthen their biosafety and other regulatory institutions and mechanisms to effectively manage biotechnology.

Thus, there is ample scope for cooperation and collaboration among the countries of the region to share and learn from their experiences, technologies, expertise, management strategy, and policy. It must, however, be recognized that ultimately it is the responsibility of individual nations to formulate and create their own country-specific policies, regulatory measures and other institutions to harness the technology.

FAO and other concerned international organizations should assist the developing countries in building and strengthening their scientific, regulatory (legislations and standards) and policy capacities. These organizations should constitute the global information clearing houses and undertake collection, collation, and exchange of value added information, knowledge, and experience. These should also provide neutral forums fora for global debate on the various issues and sometimes differing perspectives related with the use, or even no use, of biotechnology for comprehensive food security and nutritional adequacy, poverty alleviation, and environmental sustainability (FAO 2000). The proposed establishment of Asia-Pacific Bionet could provide such a forum.

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